

## Constipation, dietary fibre and the control of large bowel function

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"I have known . . . the happiness of a whole household to hang daily on the regularity of an old man's bowels. The gates of Cloacina open, the heavens smile and all goes smoothly.

'Master's bowels have not acted today', from the lips of the faithful butler and the house is shrouded in gloom."

J.F. Goodhart, 1902

Goodhart's brief cameo of late Victorian life in England is a reminder of the disproportionate influence which trivial changes in bowel habit may have on people's lives, and of the long-held belief that regularity in these matters is the *sine qua non* of healthy and effective living. Today constipation is unfairly equated with the refined habits and indolent lifestyle of the late twentieth century, when in fact it is a symptom with many causes, recognized by the lay-public and doctors alike, and clearly described in the very earliest of medical and historical writings.

The enigma of constipation lies not so much in its diagnosis but in its pathophysiology and management. These aspects of constipation have occasioned the writing of a number of classic texts on the subject, starting in 1840 with 'A treatise on the causes and consequences of Habitual Constipation' by John Burne. In his discussion of the causes of constipation, in addition to the usual pathologies that we recognize today, Burne is at pains to point out that '... inattention to the calls of Nature... the civilised life... sedentary habits and occupations... and literary pursuits...' are all important causes. He is forthright about matters which we perhaps avoid discussing with our patients today when he says 'A misplaced sense of delicacy, an absolute disregard of the calls of nature, some engagement from which persons do not at the moment liberate themselves, the inconsiderate or ill-planned situation of the closet, or of the out-of-door cabinet d'aisance, all conspire to counteract the operations of nature and to originate constipation. How often does it happen that ladies, feeling it not quite convenient to retire to the closet at

the moment they experience an admonition, defer it till a more favourable opportunity; but this opportunity having arrived their efforts are powerless; the bowel will not then act and disappointment and discomfort ensue.'

In 1909 a detailed and comprehensive 340-page account of constipation was written by Arthur Hertz (later Sir Arthur Hurst) entitled *Constipation and Allied Intestinal Disorders* in which he 'attempts to determine what part of the intestines is to blame in different forms of constipation by tracing with the X-rays the passage of food mixed with a bismuth salt through the alimentary canal'. In this book the idea of slow-transit constipation, and allied motor disorders is born.

Most recently in 1972 a distillation of new knowledge of the causes and treatment of constipation was published in *Management of Constipation* by Sir Francis Avery Jones and Edmond Godding. The popularity of this book was due partly to its timeliness, coming as it did when there was a revival of interest in dietary fibre, and to its practicality, containing the clinical experience of one of the most outstanding gastroenterologists of his time.

Although having written nothing on this subject before 1972, Sir Francis recognized in the mundane problem of constipation and its treatment by dietary fibre the start of a new understanding of colonic physiology. In *Management of Constipation* he writes 'It is also possible that the fibre-containing foodstuffs may favourably influence the bacterial activity in the colon. The influence of diet on bacteria is one which is probably of great importance to bowel activity...'. The truth of these words is already evident only 10 years after they were written both in the context of the management of constipation and of colonic function overall.

### Prevalence of constipation

Constipation, a disorder of bowel habit characterized by the passage of small amounts of hard faeces infrequently and with difficulty, is a universally

recognized and relatively common complaint. In the U.K. about 1 in 100 people consult their general practitioner each year on account of this symptom, about 400,000 consultations annually (Royal College of General Practitioners, 1979). However in population surveys as many as 10% of people consider themselves constipated or have to strain often at stool (Connell *et al.*, 1965; Thompson and Heaton, 1980). The symptom of constipation is commoner in women than men (Royal College of General Practitioners, 1979; Connell *et al.*, 1965) and women tend to have slower transit through the gut (Wyman *et al.*, 1978; Cummings *et al.*, 1984). Over the age of 65 constipation becomes increasingly common with 1 in 5 or more elderly persons suffering from this problem. Laxative use also increases with age. More than weekly use is infrequent under the age of 20 years but increases to 10–15% of the population in middle life and 20–30% at the age of 65 (Connell *et al.*, 1965; Thompson and Heaton, 1980).

### Fibre and constipation

There are many causes of constipation but those most commonly encountered in medical practice are due either to diet, inactivity, menstruation or pregnancy, drugs and to the irritable bowel syndrome. Of these five principal causes four may be treated satisfactorily with diet alone, in particular by increasing dietary fibre intake.

The use of fibre, particularly bran, to treat constipation has been practised for many years. In the 16th century Cogan wrote 'Brown bread made of the coarsest wheat flour having in it much branne when made wholly unsifted, branne and all is made into bread, filleth the belly with excrements and shortly descendeth from the stomach... I have known this experience of it that such as have been used to fine bread, when they have become costive, by eating brown bread and butter have been made soluble.'

Burne in 1840 recommends that 'Coarse brown or bran bread is very efficacious, the bran acting as a salutary stimulus to the peristaltic action of the intestines', although he also stresses the benefits of 'early rising, ... the habit of frequenting the closet regularly... exercise... a change of scene, ... figs, prunes, mustard seed and ripe fruits, ... a glass of cold water, ... and bacon'.

In 1909 Hurst writes 'One of the most valuable foods for constipation is whole-meal bread... white bread, which is made of the endosperm alone and those varieties of brown bread, such as Hovis, which are made from the endosperm and germ, contain only about one-fifth of the cellulose present in whole-meal bread. It is clear, therefore, that the substitution of whole-meal bread for white bread is a very

important part of the dietetic treatment of constipation.'

By 1936 Dimock in his M.D. Thesis for the University of Cambridge entitled *Treatment of habitual constipation by the bran method* was able to review over 50 papers reporting clinical, biochemical, radiological and physiological studies of the use of fibre in constipation. He discusses various current ideas about the way bran produces its laxative effect, which included the presence of indigestible fibre, its vitamin B content, phytin, hemicellulose, inorganic salts and the production of volatile acids from decomposition of cellulose and hemicellulose. As a result of his own observations he concluded 'My view is that bran exerts a mechanical laxative action due to its fibre content. The fibre mixes intimately with the food residues in the colon, even when bran is taken only once a day. I believe that by so doing, it not only retains moisture itself but enables the other residues in the colon to resist dehydration.'

Bulk laxatives such as ispaghula, various celluloses, agar, karaya, sterculia and psyllium were also in common use in the 1940s and were a focus of some interesting studies on their mechanism of action. This was felt at the time to relate to their capacity to absorb and retain water in the gut (Porges, 1928; Morgan, 1934; Ivy and Isaacs, 1938; Gray and Tainter, 1941; Tainter and Buchanan, 1954). However the work by Williams and Olmsted (1936a and b) which involved careful metabolic balance studies and faecal analysis of subjects ingesting various fibres prepared from peas, carrots, cabbage, corn bran, wheat bran, etc. concluded that 'Contrary to the accepted belief, the effectiveness of indigestible residues is not due primarily to the mechanical stimulus of distention but rather to chemical stimuli which arise from the destruction of hemicelluloses and cellulose by the intestinal bacterial flora. One of these stimulating products is the lower volatile fatty acids'. These studies clearly contradicted the experimental data of others and questioned the whole basis of then currently accepted beliefs about fibre. Perhaps surprisingly there followed an apparently complete loss of interest in the subject and no significant developments were reported for the next 30 years.

Attention to the effect of dietary fibre on bowel habit returned around 1970, not because of any new insights into the problem of constipation but as a result of epidemiological observations relating bowel habit to disease by Burkitt (Burkitt, 1969, 1971a and b, 1972; Burkitt, Walker and Painter, 1972) and studies by Painter on the aetiology and treatment of diverticular disease (Painter, 1968, 1969; Painter, Almeida and Colebourn, 1972). The essence of Burkitt's writings was that the notably greater prevalence of large bowel cancer, diverticular disease, appendicitis and constipation in Western countries

when compared to that in rural Africa was due to dietary differences between the two populations and in particular to the relative lack of fibre in the diet of the West. Burkitt cited as evidence for this hypothesis the fact that the rural African was rarely constipated, having a much greater stool output (400–500 g/day) than that observed in other countries such as the U.K., U.S.A. (100–200 g/day). In his paper on the aetiology of large bowel cancer (Burkitt, 1971b) he suggests that fibre benefits bowel function by speeding up transit time, diluting gut contents and favourably influencing the microbial flora. At the same time Painter was concluding a series of studies in the U.K. which he interpreted as showing that diverticular disease of the large intestine was due to lack of bulk in colonic contents. Propulsion of these contents was more difficult if they were dry, inspissated and of low volume and thus required increased muscular activity eventually leading to hypertrophy and increased intraluminal pressures. He then went on to show that contrary to current medical opinion diverticular disease could be satisfactorily treated by increasing the amount of dietary fibre in the form of wheat bran. These studies stimulated new research into the possible dietary factors determining colonic disease and into the mode of action of fibre in the colon. Much of the early work on fibre has inevitably been repeated but today, as a result of better chemical techniques and advancing knowledge of colonic physiology, new concepts have emerged with regard to the mode of action of fibre in the colon, and its role in determining colonic function.

### Dietary fibre and bowel habit

The studies of dietary fibre and large bowel function undertaken in the 1970s confirmed the long-held view that fibre has a marked effect on bowel habit (Eastwood *et al.*, 1973; Harvey, Pomare and Heaton, 1973; Cummings *et al.*, 1976, 1978). How-

ever, the better precision of present-day experimental techniques allowed these observations to be taken further. When the effects of different fibres were compared it was clear that each was qualitatively different. Table 1 shows the increases in stool weight observed when groups of healthy subjects are given similar amounts of various dietary fibre preparations over 3 week periods in controlled dietary studies. Some fibre sources such as guar and pectin have relatively minor effects on bowel habit whilst others like bran and ispaghula are much more effective at increasing stool weight.

The reasons for these differences relate to the physico-chemical properties of dietary fibre. Two factors, particle size and chemical composition of individual fibre polysaccharides, have emerged already from experimental studies as specifically affecting the mode of action of dietary fibre.

### Particle size

If exactly the same source of fibre is fed at two different particle sizes the greater particle size preparation will produce larger changes in stool output (Kirwan *et al.*, 1974; Brodribb and Groves, 1978; Heller *et al.*, 1980). The reason for this is thought to relate to the extent and rate of breakdown of dietary fibre in the large intestine. Large particles are more slowly degraded and so are more likely to survive passage through the gut. In so doing they are able to exert a physical effect on colonic function by providing both bulk to gut contents and a surface for the bacteria which allows for their more efficient metabolism. The bacteria in turn play an essential role in the control of large bowel function.

### Chemical composition

If the carbohydrates in the fibres listed in Table 1 are measured chemically and the results of this

TABLE 1. Change in mean daily stool output with 8 different fibre preparations

Preparation	n	Fibre intake (g/day)	Faecal weight (g/day $\pm$ s.d.)		% Increase for 20 g fibre intake
			Control diet	+ Fibre	
Bagasse†	9	9.4	88 $\pm$ 6	140 $\pm$ 10	124
Bran*	6	18.0	95 $\pm$ 21	197 $\pm$ 33	117
Ispaghula**	4	20.4	162 $\pm$ 44	305 $\pm$ 153	86
Cabbage*	6	18.3	88 $\pm$ 24	143 $\pm$ 40	67
Carrot*	6	20.1	117 $\pm$ 17	189 $\pm$ 39	61
Apple*	6	21.9	141 $\pm$ 48	203 $\pm$ 70	40
Pectin††	5	30.8	107 $\pm$ 55	138 $\pm$ 54	19
Guar*	3	17.2	120 $\pm$ 36	139 $\pm$ 29	17

n = number of subjects.

†from Baird *et al.*, 1977.

\*from Cummings *et al.*, 1978.

††from Cummings *et al.*, 1979b.

\*\*from Prynne and Southgate, 1979.

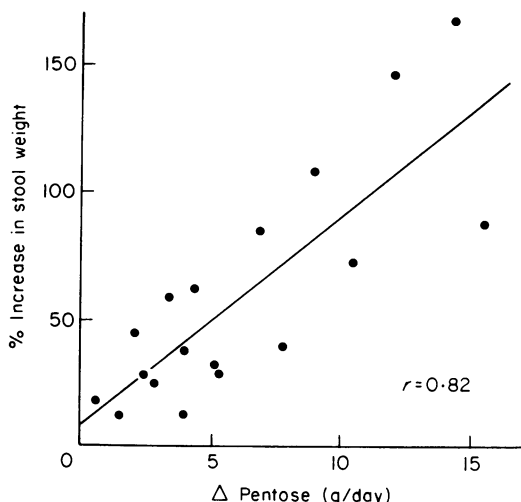


FIG. 1. Increase in mean daily stool output (% increase compared to control diet) seen in groups of healthy volunteers fed various fibre-containing preparations under controlled dietary conditions, compared with the increased intake in pentose sugars (g/day) from polymers in that fibre source. Materials were (number of studies) guar, pectin, ispaghula, soya (2), cabbage, carrot, apple and wheat in various forms (10).

Data compiled from Anderson *et al.*, 1983; Cummings *et al.*, 1976, 1978, 1979a and b, 1984; Prynne and Southgate, 1979; Schweizer *et al.*, 1983; Southgate *et al.*, 1976.

analysis compared to their effectiveness as faecal bulking agents then another relationship is evident (Fig. 1). The more pentose-containing polymers present in a fibre source the greater the increase in stool weight, other factors being equal. This associa-

tion is an intriguing one and one which is at the present time unexplained. It was initially felt that the response to pentose-containing polysaccharides was simply a reflection of the water-holding capacity of a particular fibre. However both pentose- and hexose-containing polysaccharides hold water and further research has cast doubt on the water-holding hypothesis (see later). The pentose relationship holds over a broad range of types of dietary fibre and differing experimental circumstances and it may well in the end point to a particular role for pentose sugars in microbial metabolism in the large intestine.

### The water-holding hypothesis

It has been assumed from the earliest times that fibre exerted its effect in the gut simply by virtue of its bulk. Fibrous materials were thought to act as sponges, taking up water and thereby increasing the amount of intestinal contents and causing a mechanical stimulation of peristalsis. The capacity to take up water by different types of fibre has therefore been the subject of a number of studies (Tainter and Buchanan, 1954; Gray and Tainter, 1941; McConnell, Eastwood and Mitchell, 1974). However until recently no study had compared the *in vitro* water-holding capacity of dietary fibre preparations with their effect on bowel habit in man. When this was done it was quite clear (Fig. 2) that those fibres which took up most water *in vitro*, i.e. the gel-forming polysaccharides such as guar and pectin, had the least effect on bowel habit whilst the most effective faecal bulkers such as bran held very little water on a weight for weight basis. In fact, as Fig. 2 shows, the

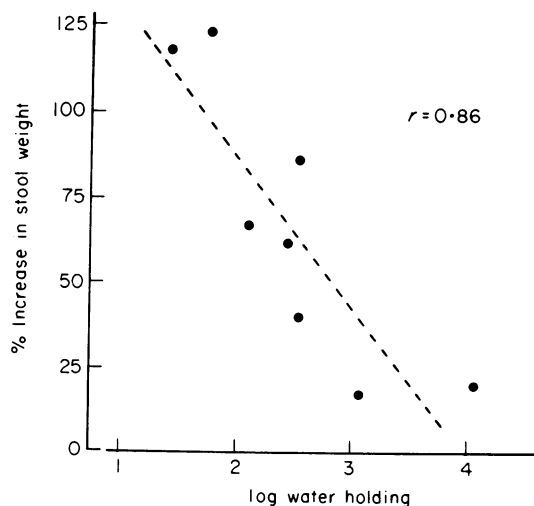


FIG. 2. The relation between (log) *in vitro* water-holding capacity of eight dietary fibre-containing preparations (in order of increasing water-holding: bran, bagasse, cabbage, carrot, ispaghula, apple, guar and pectin) and their effect on mean daily stool weight (% increase over control diet period) when fed in equivalent amounts to groups of healthy volunteers. From Stephen & Cummings, 1979.

relationship is statistically significant for the reverse of the suggested hypothesis, i.e. that substantial water-holding *in vitro* predicts a significantly smaller, rather than greater, effect on faecal bulk.

At the time this observation was made its full significance was not appreciated. In retrospect however it should have been noted that fibres which readily took up water were less effective. Water holding can probably be equated with solubility and in turn this property of fibre allows it to be more rapidly degraded by the intestinal microflora (Cummings, 1982). These more rapidly degraded fibres seem to have a less pronounced effect on faecal microbial metabolism.

### Breakdown of fibre in the gut

The most telling argument against the water-holding hypothesis is that virtually all fibre is broken down in the gut. Fibre digestion in man has been reported in the literature on many occasions in the past century. Despite this the popular view has persisted that it is not degraded although there is now ample evidence to the contrary (Cummings, 1981a). For example when fibre in mixed diets is fed to healthy subjects 70–80% of it disappears during passage through the gut (Southgate and Durnin, 1970). The cellulosic fraction tends to survive digestion better than the non-cellulosic polysaccharides and fibre from cereals better than that from fruit and vegetables. When the digestion of cabbage and bran fibre were compared in healthy subjects taking equal doses of each material then only 10% of the cabbage fibre could be recovered in faeces whilst 60% of bran fibre was excreted (Stephen and Cummings, 1980b).

Since fibre is extensively degraded it is not

surprising that its water-holding capacity is insufficient alone to explain its physiological effects in the colon. Another mechanism has to be sought whereby fibre can effect colonic metabolism. Williams and Olmsted (1936a) were probably the first to recognize the significance of the extensive breakdown of fibre in the human gut. They suggested that the faecal bulking effect of fibre could be accounted for by the stimulatory effect on colonic smooth muscle of the major end-products of fibre breakdown, the short chain, or volatile, fatty acids. This hypothesis found favour for a while because it was believed that short chain fatty acids were poorly absorbed from the human colon and therefore exerted an osmotic effect on salt and water transport in the gut (Buastos-Fernandez *et al.*, 1971). However the faeces of subjects on high fibre diets are quite unlike the watery stools seen with osmotic catharsis. Furthermore short chain fatty acids are now known to be well absorbed from the human colon (Cummings, 1981b) and their production and absorption if anything reduces the osmotic load on the colon compared with that of an equivalent amount of soluble carbohydrate (Saunders and Wiggins, 1981; Argenzio, 1978). Although their excretion increases as stool bulk increases in diarrhoeal states (Cummings, James and Wiggins, 1973) their role is probably a passive one in these circumstances.

### Fibre and microflora

A component of normal stools that has been neglected in studies of faecal bulking for many years is the microflora. Bacteria are about 80% water and therefore a potentially important water-holding component of stools. Because of their ability to resist

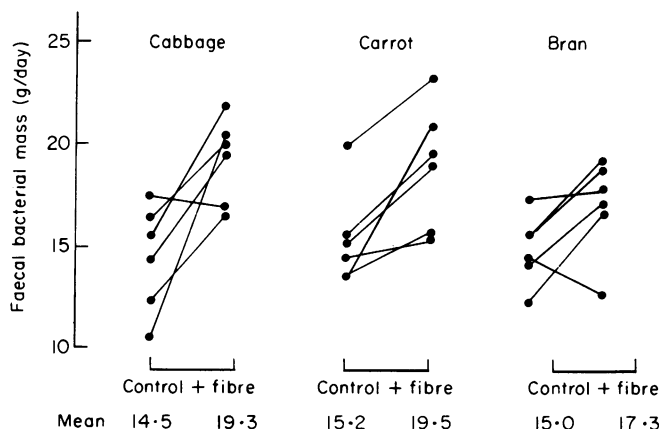


FIG. 3. Mean daily faecal excretion of microbial solids in three groups of healthy volunteers given a typical U.K. diet containing about 20 g cell-wall polysaccharides for a 3-week period and then the same diet with the addition of 18.3 g cell-wall polysaccharides from cabbage, or 19.3 g from carrot or 14.2 g from bran. From Stephen and Cummings, 1980b and Dr John Banwell (unpublished data).

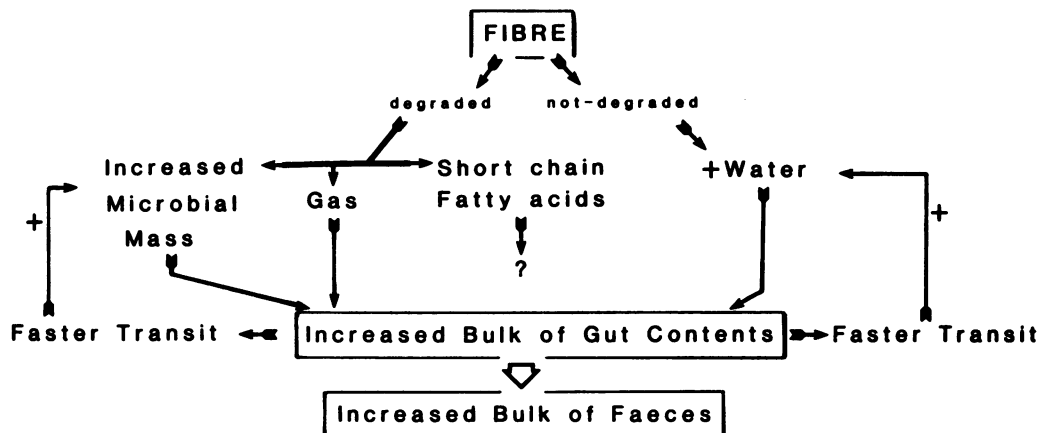


FIG. 4. Proposed way in which fermentable carbohydrates such as dietary fibre, lead to increased faecal bulk.

dehydration bacteria are more likely to retain their water against the absorptive forces of the colonic mucosa than are the cellular skeletons of plant material that remain after cooking of food and its subsequent passage through the gut.

The number of bacteria in human faeces has been estimated from direct microscopic counts as  $4 \times 10^{11}$  to  $8 \times 10^{11}$  per gram of dry faeces (Van Houte and Gibbons, 1966; Moore and Holdeman, 1975; Finegold, Attebury and Sutter, 1975). The average volume of a bacterium is considered to be  $1 \mu\text{m}^3$  and at these counts bacteria are estimated to be approximately 30–40% of the dry weight of stools. Stephen and colleagues have developed a method for fractionating human faeces which allows the contribution from microbial material to be estimated (Stephen and Cummings, 1980a). Using this technique it can be shown that bacteria comprise up to half of the faecal solids in subjects eating typical Western diets. Bacteria are therefore probably an underestimated component of human faeces and their role in any change in faecal weight may be important.

The knowledge that dietary fibre was extensively broken down in the large intestine has led to the hypothesis that one of the major roles of fibre is to provide an energy yielding substrate for microbial fermentation and in so doing lead to a stimulation in microbial growth (Cummings, Stephen and Branch, 1981). Fig. 3 shows that when dietary fibre is fed in equal amounts to groups of healthy subjects faecal microbial mass increases. This increase is not directly proportional to the amount of fibre metabolised since there is a significant change even with bran which is only partly broken down. However the control of microbial metabolism in the human colon is not solely related to the supply of carbohydrate substrates. It has been shown that the rate of passage of material through the colon also has a significant

effect on the microbial cell yield from given amounts of dietary polysaccharide (Stephen and Cummings, 1980c; Cummings, 1983).

#### Mechanism of action of dietary fibre

The way in which dietary fibre affects bowel habit cannot be explained on the basis of one simple hypothesis. Nevertheless the identification of the microbial contribution to human faecal mass adds a new dimension to theories as to how fibre brings about these changes. Fig. 4 shows that there are probably four distinct effects of fibre by which it brings about an increase in stool weight. *Firstly*, plant cell walls which resist breakdown by the microflora, e.g. because of lignification as in bran, are able to exert a physical effect on intestinal bulk by retaining water within their cellular structure. Increasing bulk stimulates colonic movement. *Secondly*, most forms of dietary fibre are extensively degraded by the microflora. The result of this is to stimulate microbial growth and a greater excretion of microbial products in faeces. This again contributes to the change in faecal mass. *Thirdly*, substances which increase bulk in the large intestine often speed up the rate of passage through the bowel. As transit time falls so the efficiency with which the bacteria grow on dietary fibre improves (Stephen, 1980; Kotarski and Salyers, 1981). Shortened transit time also leads to reduced water absorption by the colon and therefore wetter stools (Stephen and Cummings, 1980b). *Fourthly*, dietary fibre is an important source of gas in the colon since the gases hydrogen, methane and carbon dioxide are some of the principal end products of fermentation. Gas trapped within gut contents again add their bulk. These mechanisms together combine to increase stool weight.

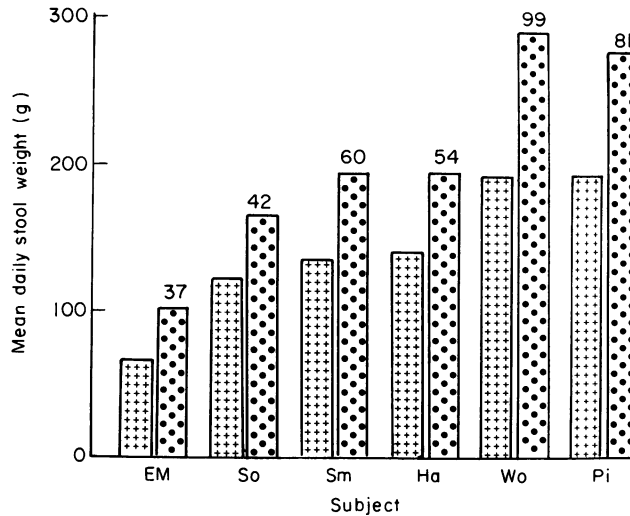


FIG. 5. Mean daily stool weight (g/day) in six subjects during the third week of either control (Western-type) diet (++) containing 22 g dietary fibre/day, or the same diet with the addition of 25.0 g/day of dietary fibre from apple (+.). Numbers above columns are the increase in stool weight seen when apple fibre was added to the diet. From Cummings *et al.*, 1978

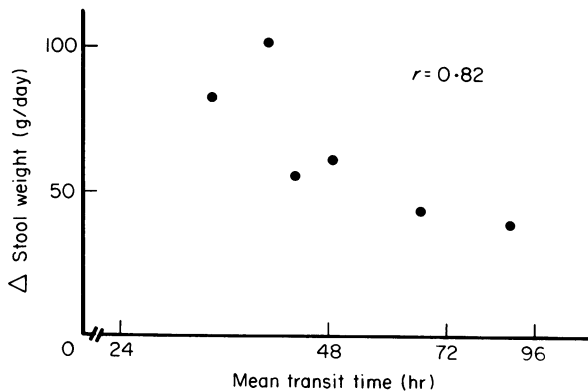


FIG. 6. Increase in stool weight (g/day) in six subjects when changing from a control diet to one including 25.0 g/day apple fibre (as in Fig. 5) in relation to their mean transit time (MTT) in hours whilst on the control diet.

### The constipated patient—a poor responder

A further observation of the mechanisms of action of dietary fibre is of importance in the treatment of constipation. When different fibres are fed to groups of individuals, contrasting responses in bowel habit are seen. However if the same fibre is fed in equal amounts to a group of individuals then each person responds in a different way. Fig. 5 shows the average daily stool weight in six healthy subjects aged 21–22 years consuming first of all a control diet containing 22 g dietary fibre for a 3-week period. Faecal weight varied from 65 to 194 g/day. When 22 g/day of fibre

from apple was added to their diets the average daily increase in faecal weight seen in each subject over the ensuing 3-weeks also varied, from 37–99 g/day. What is most notable about this effect is that the subjects who start out with the smallest stool weight also produce the smallest increase in faecal weight. In fact the response to fibre is a direct proportion of the initial faecal weight. The proportional increase in stool weight in these subjects was very similar, the mean being  $45 \pm 3.5\%$  s.e.m. This effect holds for all fibres examined so far except wheat bran.

The determinant of an individual's response to dietary fibre is probably his transit time. Subjects with the lowest stool weights whilst on the controlled diet also have the longest transit times. Fig. 6 shows that the response of an individual to dietary fibre can be predicted from his transit time, people with the longest transit times showing the smallest response in faecal weight. These data have implications for clinical practice. If it becomes desirable to increase a patient's faecal output because of constipation much more dietary fibre is required the longer the patient's transit time and the smaller the initial faecal weight. It seems therefore that the more constipated people are at a major disadvantage because of their slow transit time. In some patients fibre alone will not overcome their disability.

### Conclusion

Thus the story of an apparently mundane and oft reported observation that fibre affects bowel habit and is beneficial in constipation has led to new

insight into large bowel function. The extensive breakdown of fibre by the colonic microflora and the consequences of this fermentative process for both the colon and metabolism in general are only now being realised. Few people anticipated this development, but one who did and was instrumental in ensuring that research was encouraged in this area was Sir Francis Avery Jones.

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